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14. ABSTRACT

Two-way fully-coupled ESMF (Earth System Modeling Framework) COAMPS® (Coupled Ocean/Atmosphere Mesoscale Prediction System) simulations of the Adriatic Sea bora were performed to compare to observational data from several recent field studies as well as to an uncoupled simulation. Results show that latent and sensible heat fluxes were superior in the fully coupled run using NCOM (Navy Coastal Ocean Model) SSTs than the uncoupled run utilizing just NCODA (Navy Coupled Ocean Data Assimilation) SSTs. COAMPS winds and wind stresses produced by the bora events show mixed results when compared to the observational data. The ocean circulation pattern in the fully-coupled run responded by producing mixed results with regard to the double gyre surface current pattern that is prevalent during strong bora events.

15. SUBJECT TERMS

Coupled Ocean/Atmosphere Mesoscale Prediction System, ESMF, cyclonic

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Two-Way Atmospheric and Oceanic Coupling of the Adriatic Bora

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***Abstract*-Two-way fully-coupled ESMF (Earth System Modeling Framework) COAMPS® (Coupled Ocean/Atmosphere Mesoscale Prediction System) simulations of the Adriatic Sea bora were performed to compare to observational data from several recent field studies as well as to an uncoupled simulation. Results show that latent and sensible heat fluxes were superior in the fully coupled run using NCOM (Navy Coastal Ocean Model) SSTs than the uncoupled run utilizing just NCODA (Navy Coupled Ocean Data Assimilation) SSTs. COAMPS winds and wind stresses produced by the bora events show mixed results when compared to the observational data. The ocean circulation pattern in the fully-coupled run responded by producing mixed results with regard to the double gyre surface current pattern that is prevalent during strong bora events.**

I. INTRODUCTION

The Adriatic Sea has recently been the subject of numerous atmospheric and oceanic modeling and observational studies (e.g. Pullen et al. (2006), Pullen et al. (2007), Martin et. al. (2006), Kuzmic et al. (2007), Book et al. (2007)). Many of these studies focus on the downslope windstorms or "bora" that occur in the topographic mountain gaps of the Dinaric Alps of Croatia during the late fall and winter months. The specific characteristics of each bora event are dependent upon the synoptic meteorological background flow (Jurcec (1988)). For instance, a bora event forced by northeasterly winds from a surface anticyclone or high to the north of the Dinaric Alps is termed "anticyclonic", and a bora event forced by northeasterly winds from a surface cyclone or low southeast of the Diurnic Alps is termed "cyclonic". In general, the cyclonic bora produces stronger winds while the boundary layer depth tends to be shallower (Defant, 1951).

Due to the nature of these bora events and the fact that these winds traverse the Adriatic Sea in the form of mesoscale jet flows, this region is of particular interest to air/sea interaction studies at the mesoscale level. Most importantly, it has been found that the circulation patterns of the northern Adriatic Sea are heavily influenced by bora jet flows. In fact, several comprehensive studies utilizing fifteen bottom-mounted Acoustic Doppler Current Profilers (ADCPs) were deployed from September 2002 until May 2003 in the northern Adriatic Sea to measure currents associated with the bora (Book et al. (2007), Martin et al. (2006), Kuzmic et al. (2007)). High levels of current variability were observed which were heavily influenced by the number, strength, and duration of bora events that occurred over a period of time. This variability is highlighted by the emergence of a double-gyre surface current pattern in the northern Adriatic associated with the onset of a bora episode. In order to resolve both the bora jets and the subsequent double gyre current patterns, it is necessary to employ a high-resolution atmospheric and ocean model to accurately depict the temporal and spatial positions of these features.

This validation exercise of the ESMF two-way coupled COAMPS/NCOM (COAMPS version 5.0) modeling system is based upon two studies conducted at the Naval Research Laboratory. Several stations are used to examine the meteorology at representative locations in the northern Adriatic, (Pullen et al. (2007), Dorman et al. (2007)) Acqual Alta (Venice), Ancona, Veli Rat, and Azalea (Fig. 2). As described in Dorman et al. (2007), the over water station on the northwest coast is the ISMAR-CNR Institute Venice (Acqua Alta) tower located 16 km off the main inlet leading to Venice. The over water station on the western coast is the ISMAR-CNR Ancona Section meteorological mast positioned 2 km offshore near Ancona, Italy. Shortwave radiation at Ancona was measured at a building in Ancona Harbor. EACE took the Veli Rat meteorological data while the Scripps Institution of Oceanography instrumented the Italian AGIP gas platform Azalea-B.

In addition, ocean current data obtained from ADCPs in February 2003 are utilized for the NCOM portion validation. As described by Book et al. (2007), bottom-mounted ADCPs were deployed by the Naval Research Laboratory (NRL) during the Adriatic Circulation Experiment (ACE) together with the NATO Undersea Research Centre (NURC) as a Joint Research Project (JRP) from September 2002 to May 2003. ACE/JRP moorings consisted of 14 trawl-resistant bottom-mounted ADCPs (Perkins et al. (2000)) distributed throughout portions of four mooring sections. Instruments on each ADCP measured the ocean currents throughout the water column. The current data utilized in this validation report from the ADCPs was quality-controlled and processed prior to utilization, which is described in Book et al. (2007). The moorings used in this validation are the VR1, VR2, VR4, VR5, VR6, KB1, CP2, and CP3 moorings shown in Fig. 2.

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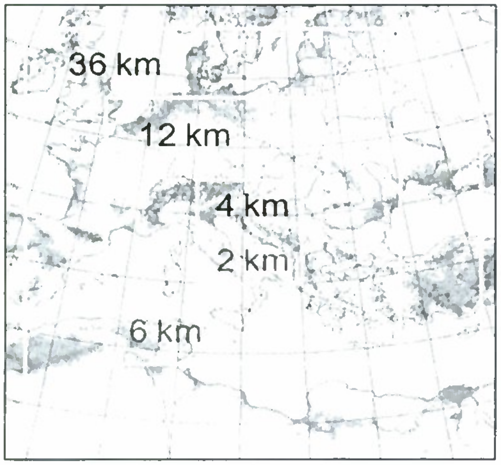


Fig. 1: Atmospheric and ocean grid setup for the Adriatic Sea. The resolution for the atmospheric nests (black) and the ocean nests (purple) are indicated.

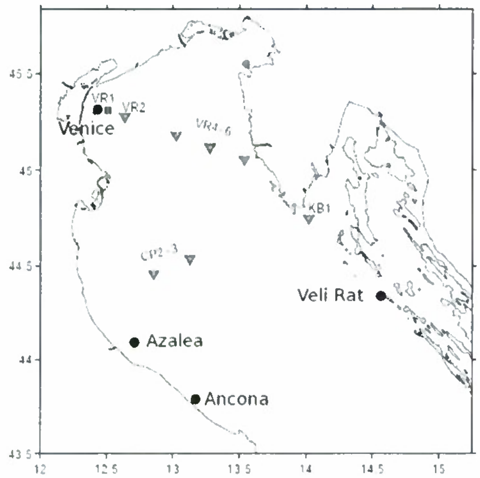


Fig. 2: Locations of moorings deployed in the northern Adriatic during the winter of 2002/2003 (Book et al. (2007)). Red triangles are BARNY moorings deployed by NRL and NURC. The purple square indicates the location of a JRP ADCP at the Acqua Alta Tower (Venice) of the Institute for the Study of the Dynamics of Great Masses (Italy). The green circle is a mooring deployed by the National Institute of Biology. The black circles indicate the locations of the four stations for the atmospheric validation as discussed in the introduction.

II. MODEL SETUP DESCRIPTION

The COAMPS model setup closely resembles the setup in Pullen et al. (2007). The COAMPS Adriatic Sea configuration is a triply nested (36, 12, 4 km horizontal resolution) domain where nest 3 extends from 39.6°N to 47.3°N and 10.4°E to 20.6°E with horizontal dimensions of 187 × 205 (Fig. 1). There are 40 vertical terrain-following levels. At 00 UTC and 12 UTC of each day a data assimilation cycle is initiated using the prior 12-hr forecast as background, and incorporating quality-controlled observations from aircraft, radiosondes, satellite, ship, and surface stations. A multi-variate optimum interpolation (MVOI) analysis is used for satellite measurements. The length of the model run extends from 25 January 2003 to 21 February 2003, a period of 28 days.

The ocean model NCOM (Martin, 2000) configuration consists of two nests (6 and 2 km horizontal resolution) where nest 2 covers approximately the same area as nest 3 in the atmospheric model (Fig. 1). There are a total of 50 vertical levels of which 36 are sigma coordinates in the upper 190 m of the water column. NCOM is initialized using global NCOM hindcast data while the atmospheric and ocean models are coupled every 12 minutes through exchange grid processes.

III. ATMOSPHERIC MODEL VALIDATION (COUPLED AND UNCOUPLED)

The ESMF two-way coupled run is compared to an uncoupled run and to the observational data at several stations in the northern Adriatic as discussed in the introduction. For the uncoupled run, the ocean to atmosphere interaction is shut off , i.e. there is no heat flux feedback back to the atmosphere from the NCOM SSTs. Table 1 summarizes the coupled and uncoupled COAMPS statistics for the four stations in the northern Adriatic for wind stress, net heat flux, sensible heat flux, and latent heat flux.

In terms of wind stress, Velirat and Acqua Alta (Venice) are the stations closest in proximity to a bora jet flow (Fig. 3) and have the largest wind stresses in both the observations and in COAMPS. When compared to the observations, the mean wind stress in COAMPS was larger at Velirat and smaller at Acqua Alta in both the coupled and uncoupled runs. However, the smaller wind stresses at Acqua Alta in COAMPS may be attributed to the intensity and positional differences of the Trieste bora jet compared to the observations. Pullen et al. (2007) COAMPS runs show a Trieste jet that is stronger at the surface and located further to the north of the new COAMPS runs in this report. Further investigation of the new COAMPS results revealed that strong winds were located just above the surface in relation to the Trieste jet and that there may be a issue with the stronger winds not mixing down to the surface in the model. However, the differences between the wind stresses between the coupled and uncoupled COAMPS run were small, i.e., the RMS errors for wind stress were slightly smaller in the coupled run compared to the uncoupled run. Inspection of the wind stress time series show good agreement ,especially at Veli Rat; however, the wind stress at Acqua Alta is shown to be less due to the differences in the Trieste jet strength and position (Fig. 5 and 6).

The sensible, latent, and net heat fluxes show some overall improvement in the coupled run than compared to the uncoupled run. The mean bias was almost uniformly smaller for the coupled run for both the latent and sensible heat fluxes at all four Adriatic stations. Therefore, the RMS errors for the heat fluxes primarily improved in the coupled run. Additionally, the correlation coefficients were quite high for the latent heat fluxes at most of the stations and the correlation coefficient for the sensible heat flux was very high for Velirat, the station closest to a bora jet. Overall, the heat flux correlation coefficients were slightly higher in the coupled run compared to the uncoupled run. As shown in the time series for heat fluxes, COAMPS tended to overestimate the total heat flux, while the sensible heat fluxes in COAMPS showed an overall consistent bias throughout the simulation at Veli Rat and Acqua Alta (Fig. 5 and 6).

In addition to the data at the four Adriatic stations, Jacopo Chiaggato of NURC provided some 5 m wind data for February 2003 from a mooring located at 13.55°E and 45.55°W in the Gulf of Trieste for comparison to the Trieste bora jet. The comparison of 10 m COAMPS winds to the buoy data also confirms that COAMPS is underestimating the strength and/or spatial position of the Trieste bora jet near the surface. The u and v components of the wind and the total wind were underestimated in COAMPS (Table 1). The total wind for the coupled run was nearly 2.3 m/s underestimated, while the uncoupled run showed a slight improvement of 1.8 m/s underestimation (mainly in the u component of the wind). However, the correlation coefficient was quite high for the winds, indicating that COAMPS was capturing the onset and offset of the Trieste bora jet to quite a high degree.

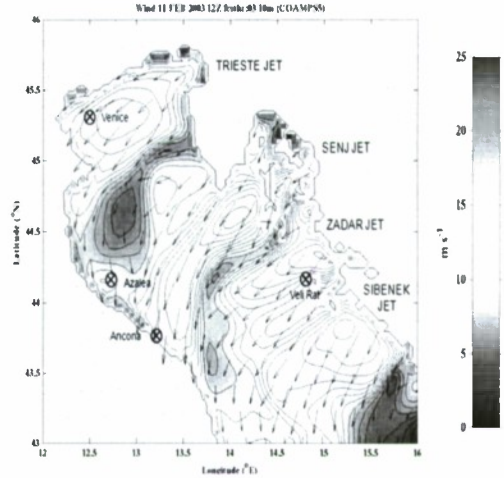


Fig. 3: Location of several stations (Acqua Alta (Venice), Azalea, Ancona, and Veli Rat) with respect to several bora jets.

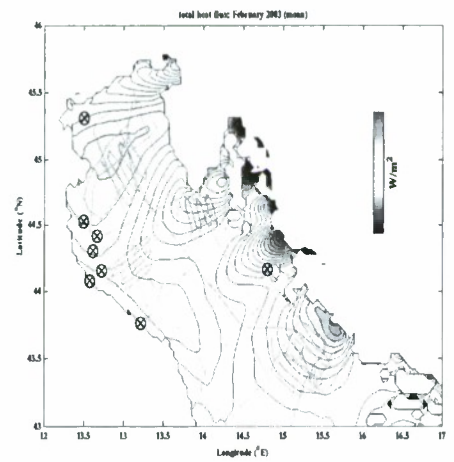
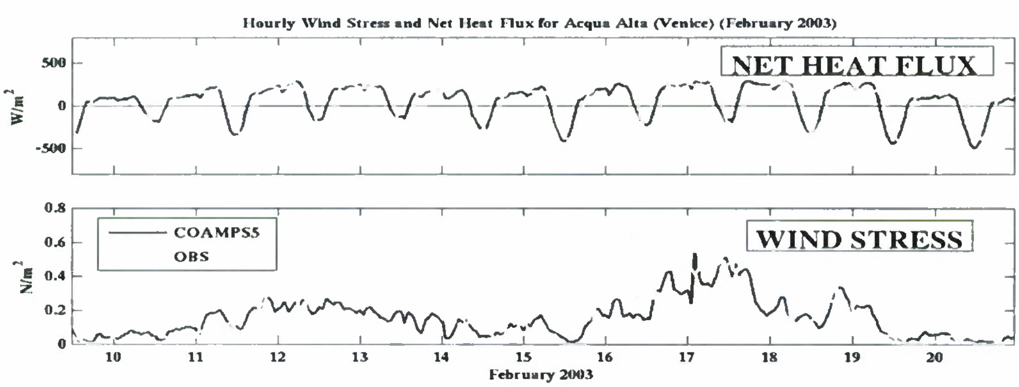


Fig. 4: Track of the ship R/V Knorr, 1-21 February 2003 from Pullen et al. (2006).

Ship data from the R/V Knorr (Fig. 4) was also provided by Julie Pullen, formerly of NRL, for comparison of COAMPS wind stresses and heat fluxes. The Knorr made 10-min averaged meteorological measurements over the northern Adriatic from 31 January to 24 February 2003. For the period 1 February to 21 February 2003, COAMPS did quite well with regards to estimating the wind stress (Table 1). The uncoupled run wind stresses showed an almost negligible improvement over the coupled run with regard to the mean bias, RMSE, and correlation coefficient. The mean bias was very small for both the latent and sensible heat fluxes in both the coupled and uncoupled runs, while the mean bias for the total heat flux was smaller for the uncoupled run. The heat flux correlation coefficients were good, but similar, overall for both the coupled and uncoupled runs.



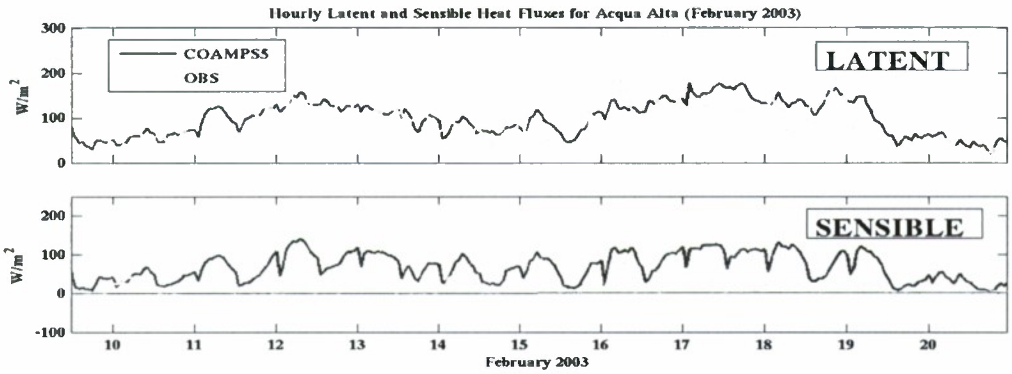


Fig. 5: Hourly wind stress, latent, sensible, and total heat fluxes for the fully-coupled COAMPS run and observations at Acqua Alta (Venice).

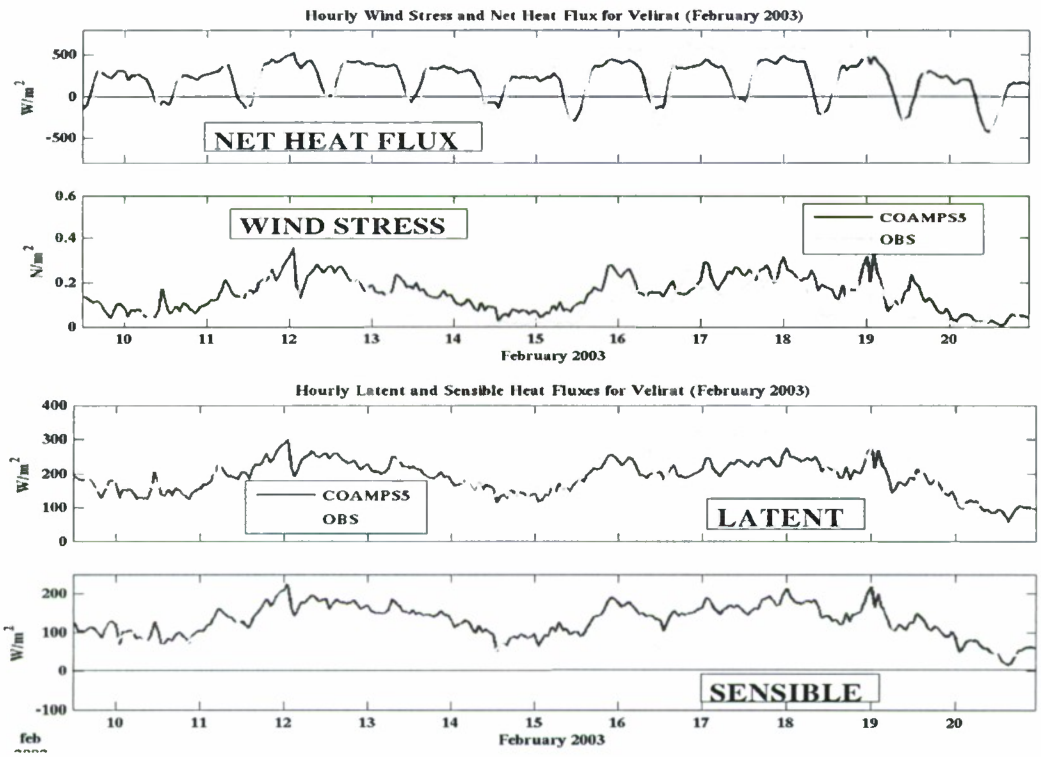


Fig. 6: Hourly wind stress, latent, sensible, and total heat fluxes for the fully-coupled COAMPS run and observations at Veli Rat.

IV. NCOM MODEL VALIDATION (COUPLED ONLY)

As noted, northern Adriatic oceanographic conditions are strongly influenced by the onset of bora jet flows. The shallowness of the water column combined with pronounced heat loss during the winter due to wind-induced mixing from bora events destabilizes the water column and enforces almost complete homogeneity. The presence of freshwater inflow from surrounding rivers also adds to the complexity of the oceanographic conditions.

Measurements to compare the observed gyral response to the fully-coupled COAMPS runs were evaluated using techniques used by Kuzmic et al. (2007). These include calculations of the magnitude of the complex correlation coefficient

and the angular displacement, or mean directional error, between the measured ADCP and NCOM model currents following Kundu (1976)):

$$\rho = \frac{\langle u_o u_m + v_o v_m \rangle + i\langle u_o v_m - u_m v_o \rangle}{\sqrt{\langle u_o^2 + v_o^2 \rangle} \cdot \sqrt{\langle u_m^2 + v_m^2 \rangle}} \tag{1}$$

$$\varphi = arctg \frac{\langle u_o v_m - u_m v_o \rangle}{\langle u_o u_m + v_o v_m \rangle} \tag{2}$$

where u and v are the east-west and north-south, observed (o) or modeled (m), demeaned velocity components and the brackets represent time average. The complex correlations were computed for each ADCP station as a function of depth based on the closest corresponding NCOM level to each ADCP bin. It is important to note that the complex correlation coefficients take in account *both* the current speed and direction.

Eight ADCP sites were chosen to evaluate the Adriatic Sea response to the bora flow for 1 February to 21 February 2003. VR1, VR2, VR4, VR5, and VR6 were utilized to compare COAMPS to the double gyre current formation resulting from the bora winds (Fig. 2). This double gyre formation is dependent upon the strength and position of the Trieste and Senj bora jets (Fig. 3). As stated in the atmospheric validation section, the Trieste jet was found to be weaker in COAMPS with a southward displacement of the bora jet axis when compared to observations. Therefore, the resultant wind stress curl field is also displaced southward, which ultimately shifts the double gyre current pattern southward. (It is also important to note that uncertainties in the current speed and direction from the observational data has been calculated to be +/- 0.5 cm/s and +/- 10 degrees for 300 kHz ADCP sites and +/- 0.3 cm/s and +/- 4 degrees for SS2, VR1, and VR4 with higher-frequency ADCP sites VR1 and VR4 (Book et al. (2007)). Also, individual speed uncertainties all vary less than 0.1 cm/s from these medians, but individual directional uncertainties can vary more because they are inversely proportional to mean speeds.)

The ADCP sites, VR1 and VR2, are located on the northern flank of the cyclonic gyre in the northern Adriatic Sea. The complex correlations were quite high at VR2, while both VR1 and VR2 show small mean directional errors in the COAMPS run (Table 2). The complex coefficients are fairly uniform throughout the entire column for each of the ADCPs VR1 and VR2 (which is basically true for all the ADCPs shown in this study). This is indicative that the flow is indeed cyclonic in COAMPS with only small deviations from the mean direction of the current, especially at VR2. This is also illustrated in the compass diagrams where the red vectors indicate the current flow during the primary bora event of 11 February to 21 February 2003. There is good agreement with respect to the observations at VR1 (not shown) and excellent agreement at VR2 (Fig. 6) where mean directional errors were generally less than 10-15 degrees.

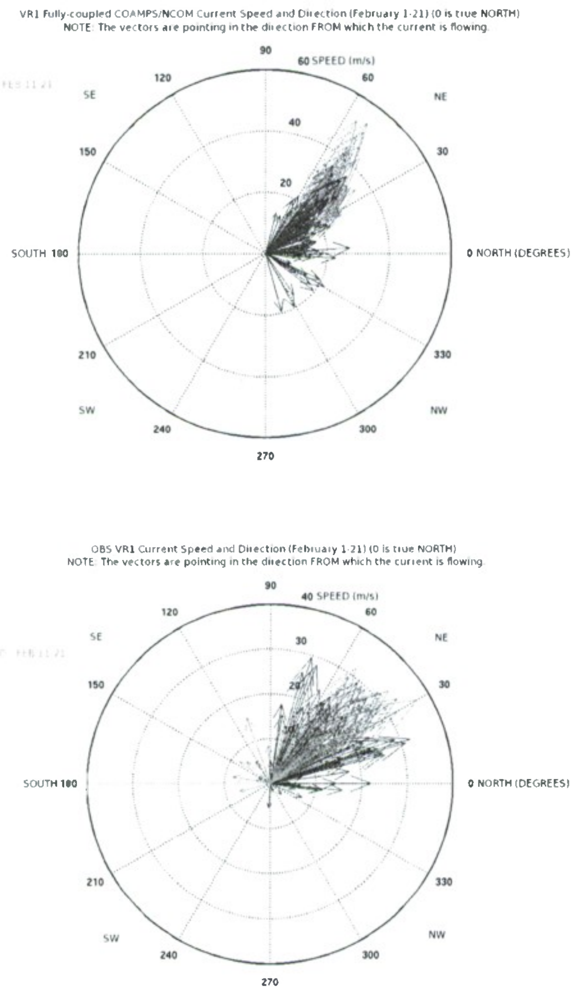


Fig. 7: Compass diagrams indicating speed and direction of winds at VR1 for 1-21 February 2003. Red vectors indicate the period 11-21 February 2003. Top: Two-waycoupled COAMPS Bottom: Observations

However, the ADCP stations VR4, VR5, and VR6 are crucial to determining whether the model is accurately representing the double gyre current pattern. It is in this region of the Adriatic Sea that the inflection of the double gyre current develops with the northern primary cyclonic gyre encompassing a much larger area than the smaller, yet distinct, anticyclonic gyre positioned just to the east or southeast of the cyclonic gyre. The complex correlations at these sites were generally quite low when compared to the observations, confirming the notion that the double gyre pattern, albeit present in the COAMPS run, is shifted relative to the true observations. In general, the mean directional errors show a 20-40 degree difference between the COAMPS run and observations and the negative signs indicate a circulation pattern that must be shifted south and east to obtain the directions indicated by the errors. These errors are also shown quite well in the compass diagrams at each of the ADCP sites as well (not shown). These errors iterate the fact that small and subtle differences in the juxtaposition of the bora jets may induce large errors in the model output when compared to the observational data. However, it is important to note that even though COAMPS did produce errors in the position of the double gyre, the model is performing as such by shifting the double gyre southward based on the southward displacement of the Trieste bora jet axis.

Further south in the northern Adraitic Sea, the ADCP sites at CP2, CP3, and KB1 are closely associated with the Senj bora jet. The currents can be quite variable at these sites depending on the strength and position of the Senj bora jet and its axis during the winter months. In terms of the complex correlation coefficient, the values at CP2 are quite low compared to the values at CP3, which can be attributed to the differences in extent and intensity of the Senj bora jet in the COAMPS run. The mean directional errors are quite good at CP3, generally less that 15 degrees throughout the depth of the column, while the mean directional errors are quite poor at CP2. KB1, which is located just offshore the Istrian Peninsula and in close proximity to the origin of the Senj jet, had a mean directional error throughout the column of less than 15 degrees which can be considered good agreement, and a complex correlation that was only slightly higher than the values at VR4, VR5, and VR6.

Comparison of the uncoupled and coupled runs yield mixed results with regard to the ADCP data (Table 3). There was an overall slight improvement in the coupled runs; however, since the ocean is still being forced by the atmospheric winds of COAMPS, a similar oceanic current pattern to the coupled run was present. The mean directional error at VR4 was much improved in the coupled run (an approximately 30 degree improvement); however, there were no real improvements at VR5 and VR6 in the coupled run.

V. CONCLUSIONS

Overall, the fully coupled COAMPS model run for the Adriatic Sea shows improvements over the uncoupled run, especially with regard to heat fluxes that are produced by the NCOM SSTs in the fully coupled run versus the NCODA SSTs in the uncoupled run. The correlation coefficients for the winds, wind stresses, and heat fluxes showed no appreciable differences between the coupled and uncoupled runs, while the RMSE for the winds for both the R/V Knorr and Gulf of Trieste buoy were only slightly lower for the uncoupled run.

The NCOM validation results for the fully-coupled run show that the surface currents are sensitive to both the strength and position of the Trieste and Senj bora jets. The discrepancies between the NCOM results and the observations can largely be attributed to the southward shift of the Trieste jet in the atmospheric model. The wind stress curl pattern associated with the COAMPS produced a double gyre surface current pattern that is shifted slightly southward compared to the mooring observations. The fully-coupled run showed some slight improvements in the current speed and direction at several of the ADCP stations; however, since the wind forcing was similar for both the coupled and uncoupled runs, little improvement in the double gyre current pattern was noted.

VI. REFERENCES

Book, J. W., H. Perkins, R. P. Signell, and M. Wimbush (2007), The Adriatic Circulation Experiment winter 2002/2003 mooring data report: A case study in ADCP data processing, Memo. Rep. NRL/MR/7330-07-8999, U. S. Naval Res. Lab., Stennis Space Center, MS.

Book, J. W., R. P. Signell, and H. Perkins (2007), Measurements of storm and nonstorm circulation in the northern Adriatic: October 2002 Through April 2003, J. Geophys. Res., 112, C11S92, doi:10.1029/2006JC003556.

Defant, F. (1951), Local winds, in Compendium of Meteorology, edited by T. F. Malone, pp. 655-672, Am. Meteorol. Soc., Boston, MA.

Dorman, C. E., et al. (2006), February 2003 marine atmospheric conditions and the bora over the northern Adriatic, J. Geophys. Res., 111, C03S03, doi:10.1029/2005JC003134.

Jurcec, V. (1988), The Adriatic frontal bora type, Croatian Meteorol., 23, 13-25.

Kundu, P. K. (1976), Ekman veering observed near the ocean bottom, J. Phys. Oceanogr., 6, 238-242.

Kuzmic, M., I. Janekovic, J. W. Book, P. J. Martin, and J. D. Doyle (2006), Modeling the northern Adriatic double-gyre response to intense bora wind: A revisit, J. Geophys. Res., 111, C03S13, doi:10.1029/2005JC003377.
Martin et al. (2007)

Martin, P. J., J. W. Book, and J. D. Doyle (2006), Simulation of the northern Adriatic circulation during winter 2003, J. Geophys. Res., 111, C03S12, doi:10.1029/2006JC003511.

Perkins, H. T., F. de Strobel, and L. Gualdisi (2000), The Barney Sentinel Trawl-resistant ADCP bottom mount: Design, testing, and application, IEEE J. Oceanic Eng., 25, 430-436.

Pullen, J., J. D. Doyle, and R. Signell (2006), Two-way air-sea coupling: a study of the Adriatic, Mon. Weather Rev., 134(5), 1465-1483.

Pullen, J., J. D. Doyle, T. Haack, C. Dorman, R. P. Signell, and C. M. Lee (2007), Bora event variability and the role of air-sea feedback, J. Geophys. Res., 112, C03S18, doi:10.1029/2006JC003726.

Table 1: Number of Observations (N), model and observational mean and standard deviation, correlation coefficient (CC), mean bias (MB), and root mean square error (RMSE) for the coupled [c] and uncoupled [u] simulations for the four stations in the Adriatic (Acqua Alta (Venice), Azalea, Ancona, and Veli Rat), Gulf of Trieste buoy observations, and the ship R/V Knorr for 1-21 February 2003.

COAMPS5 Atmospheric Parameter Comparisons to Observations

WIND STRESS (N m^{-2})

Platform	N	obs mean	obs std	COAMPS5 mean [c]	COAMPS5 mean [u]	model std [c]	model std [u]	CC [c]	CC [u]	MB [c]	MB [u]	RMSE [c]	RMSE [u]
Velirat	276	0.092	0.070	0.147	0.154	0.077	0.079	0.74	0.74	-0.05	-0.06	0.076	0.082
Azalea	288	0.063	0.057	0.106	0.120	0.061	0.071	0.51	0.53	-0.04	-0.06	0.072	0.085
Ancona	480	0.085	0.075	0.057	0.088	0.063	0.079	0.52	0.50	0.03	0.00	0.074	0.077
Acqua Alta	480	0.151	0.168	0.118	0.135	0.101	0.111	0.79	0.78	0.03	0.02	0.112	0.108

NET HEAT FLUX (W m^{-2})

Platform	N	obs mean	obs std	COAMPS5 mean [c]	COAMPS5 mean [u]	model std [c]	model std [u]	CC [c]	CC [u]	MB [c]	MB [u]	RMSE [c]	RMSE [u]
Velirat	276	280	296	197	228	208	207	0.95	0.91	83	51	144	145
Azalea	288	15	164	41	152	117	134	0.82	0.77	-25	-137	99	172
Ancona	480	101	112	-19	151	125	134	0.57	0.55	120	-50	163	129
Acqua Alta	480	62	190	49	131	167	179	0.83	0.82	12	-69	108	130

SENSIBLE HEAT FLUX (N m^{-2})

Platform	N	obs mean	obs std	COAMPS5 mean [c]	COAMPS5 mean [u]	model std [c]	model std [u]	CC [c]	CC [u]	MB [c]	MB [u]	RMSE [c]	RMSE [u]
Velirat	276	88	32	130	142	42	44	0.81	0.80	-42	-54	49	60
Azalea	288	-1	7	40	87	29	38	0.34	0.36	-42	-88	50	95
Ancona	480	27	21	16	86	21	37	0.40	0.37	11	-59	25	68
Acqua Alta	480	13	15	59	93	34	44	0.55	0.53	-46	-79	54	88

LATENT HEAT FLUX (W m^{-2})

Platform	N	obs mean	obs std	COAMPS5 mean [c]	COAMPS5 mean [u]	model std [c]	model std [u]	CC [c]	CC [u]	MB [c]	MB [u]	RMSE [c]	RMSE [u]
Velirat	276	242	74	188	206	48	50	0.74	0.74	54	37	74	62
Azalea	288	47	30	76	141	28	41	0.62	0.62	-29	-95	38	99
Ancona	480	71	33	40	138	24	43	0.45	0.42	31	-66	44	79
Acqua Alta	480	71	41	88	135	38	47	0.78	0.76	-17	-64	31	71

GULF OF TRIESTE BUOY OBSERVATIONS - FEBRUARY 1-21, 2003

LOCATION: LON: 13.55E LAT: 45.55W

WIND (m s^{-1})

Variable	N	obs mean	obs std	COAMPS5 mean [c]	COAMPS5 mean [u]	model std [c]	model std [u]	CC [c]	CC [u]	MB [c]	MB [u]	RMSE [c]	RMSE [u]
U-wind	480	-6.14	4.97	-4.10	-4.51	3.11	3.33	0.72	0.73	-2.04	-1.64	4.05	3.77
V-wind	480	-3.20	3.30	-2.33	-2.32	2.71	2.89	0.54	0.47	-0.87	-0.88	3.04	3.32
Total Wind	480	7.94	4.52	5.66	6.10	2.67	2.81	0.67	0.65	2.29	1.84	4.07	3.87

Ship Data (KNORR) - FEBRUARY 1-21, 2003

Variable	N	obs mean	obs std	COAMPS5 mean [c]	COAMPS5 mean [u]	model std [c]	model std [u]	CC [c]	CC [u]	MB [c]	MB [u]	RMSE [c]	RMSE [u]
Wind Stress	480	0.179	0.181	0.151	0.160	0.142	0.148	0.47	0.49	0.028	0.019	0.171	0.170
Net Heat Flux	480	273	219	171	195	201	204	0.70	0.70	102	78	193	183
Sensible Heat Flux	480	93	58	95	102	57	60	0.63	0.64	-2	-9	50	51
Latent Heat Flux	480	185	90	167	181	75	80	0.51	0.53	18	5	85	84

Table 2: Two-Way Complex correlation coefficients (top) and mean directional error (bottom) for eight Adriatic Sea moorings (VR1, VR2, VR4, VR5, VR6, CP2, CP3, and KB1). Green indicates good results.

NCOM level (m)	Mooring level (m)	CC							
		VR1	VR2	VR4	VR5	VR6	CP2	CP3	KB1
1.762	1.708	0.17							
2.554	2.708	0.18	0.62	0.15		0.10			
3.477	3.708	0.22	0.60	0.23	0.16	0.17	0.19	0.32	0.29
4.552	4.708	0.27	0.59	0.22	0.17	0.16	0.14	0.26	0.30
5.806	5.708	0.32	0.59	0.18	0.21	0.16	0.14	0.25	0.29
7.268	7.208	0.36	0.58	0.18	0.22	0.17	0.14	0.24	0.29
8.971	8.708	0.40	0.57	0.22	0.24	0.17	0.12	0.23	0.29
10.957	10.708	0.47	0.54	0.21	0.26	0.16	0.08	0.23	0.28
13.271	13.208	0.46	0.52	0.23	0.28	0.16	0.05	0.20	0.27
15.968	16.4287		0.51	0.26	0.28	0.16	0.09	0.22	0.25
19.112	19.4287		0.48	0.26	0.28	0.16	0.15	0.22	0.21
22.777	22.5481			0.28	0.27	0.19	0.22	0.22	0.27
27.049	27.0481			0.30	0.31	0.17	0.24	0.30	0.31
32.027	32.3767						0.27	0.33	0.28
37.831	37.3767						0.29	0.33	0.15
44.595	44.8471								0.17

COAMPS current directional errors (degrees) compared to observation moorings (February 1-21, 2003)

NCOM level (m)	Mooring level (m)	VR1	VR2	VR4	VR5	VR6	CP2	CP3	KB1
1.762	1.708	4.71							
2.554	2.708	-4.42	-5.98	-32.50		-61.34			
3.477	3.708	-11.93	-5.03	-27.85	-29.22	-33.41	76.79	7.22	6.74
4.552	4.708	-11.00	-2.92	-31.64	-25.62	-21.37	-74.96	-5.18	7.94
5.806	5.708	-8.61	-0.84	-36.43	-32.89	-29.21	-64.93	-9.29	5.07
7.268	7.208	-3.98	1.94	-38.39	-32.31	-19.39	-66.76	-6.15	3.35
8.971	8.708	1.81	2.36	-33.85	-35.40	-20.94	-57.50	0.58	-2.47
10.957	10.708	5.53	6.90	-36.15	-34.90	-16.41	-65.70	0.35	-2.13
13.271	13.208	1.41	10.51	-31.02	-35.89	-18.63	85.57	2.92	-2.00
15.968	16.4287		15.21	-30.82	-38.48	-18.30	4.64	9.54	-1.07
19.112	19.4287		22.69	-28.34	-39.95	-21.45	-9.76	5.79	9.98
22.777	22.5481			-31.63	-33.63	-25.52	7.31	12.45	9.42
27.049	27.0481			-27.20	-45.31	-28.56	10.66	17.53	10.66
32.027	32.3767						-0.18	23.90	8.29
37.831	37.3767						-0.55	35.76	8.04
44.595	44.8471								7.76

Table 3: Uncoupled complex correlation coefficients (top) and mean directional error (bottom) for eight Adriatic Sea moorings (VR1, VR2, VR4, VR5, VR6, CP2, CP3, and KB1). Green indicates good results.

Uncoupled Complex correlations for COAMPS gyral response compared to observation moorings (February 1-21, 2003)

NCOM level (m)	Mooring level (m)	CC							
		VR1	VR2	VR4	VR5	VR6	CP2	CP3	KB1
1.762	1.708	0.17							
2.554	2.708	0.18	0.53	0.16		0.11			
3.477	3.708	0.22	0.51	0.22	0.16	0.16	0.17	0.35	0.35
4.552	4.708	0.27	0.50	0.21	0.16	0.17	0.12	0.31	0.36
5.806	5.708	0.32	0.50	0.17	0.19	0.17	0.13	0.28	0.34
7.268	7.208	0.37	0.49	0.15	0.20	0.17	0.15	0.29	0.34
8.971	8.708	0.47	0.47	0.21	0.21	0.16	0.14	0.27	0.35
10.957	10.708	0.46	0.44	0.20	0.23	0.15	0.11	0.27	0.35
13.271	13.208	0.24	0.42	0.21	0.25	0.15	0.06	0.24	0.36
15.968	16.4287		0.39	0.23	0.24	0.14	0.01	0.26	0.34
19.112	19.4287		0.36	0.24	0.22	0.16	0.08	0.24	0.26
22.777	22.5481			0.26	0.21	0.16	0.13	0.23	0.22
27.049	27.0481			0.29	0.25	0.17	0.18	0.27	0.22
32.027	32.3767						0.20	0.24	0.23
37.831	37.3767						0.20	0.25	0.19
44.595	44.8471								0.20

Uncoupled COAMPS current directional errors (degrees) compared to observation moorings (February 1-21, 2003)

NCOM level (m)	Mooring level (m)	VR1	VR2	VR4	VR5	VR6	CP2	CP3	KB1
1.762	1.708	5.67							
2.554	2.708	-6.25	-4.49	-62.45		-55.16			
3.477	3.708	-13.34	-5.79	-52.98	-15.81	-32.69	-84.98	10.14	25.62
4.552	4.708	-12.24	-2.98	-48.51	-20.00	-19.41	63.20	-1.13	25.26
5.806	5.708	-8.61	-1.41	-55.93	-23.48	-20.17	-47.47	-1.29	24.55
7.268	7.208	-5.67	1.38	-58.13	-24.59	-20.00	35.07	-0.27	23.36
8.971	8.708	3.26	0.40	-50.32	-28.42	20.71	-22.83	7.61	21.42
10.957	10.708	6.65	4.81	-50.13	-24.61	-18.30	-8.69	10.09	23.93
13.271	13.208	2.54	7.97	-44.41	-26.57	-18.92	5.81	11.63	19.07
15.968	16.4287		20.68	-45.13	-29.90	-20.12	-21.59	15.54	11.39
19.112	19.4287		33.34	-40.51	-33.68	-13.90	-16.98	14.35	3.13
22.777	22.5481			-42.98	-33.71	-11.52	14.64	14.95	-2.69
27.049	27.0481			-34.78	-39.20	-10.32	24.37	16.33	-8.77
32.027	32.3767						11.57	15.87	-16.59
37.831	37.3767						9.23	20.63	-26.71
44.595	44.8471								-27.70